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Analysis of the nighttime lower ionosphere for equatorial, low and middle latitudes over a region from 30°E and 60°E

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Abstract

We present 4-year study of the nighttime lower ionosphere height (h_N) behavior for equatorial, low and middle latitudes over a region from 30°E to 60°E. The results show that h_N oscillates with semiannual (SAO) and annual (AO) periodicity, being SAO dominant for low and equatorial latitudes, while AO seems to be significant for middle latitudes. For equatorial and middle latitudes, h_N shows negative correlation with the mesospheric temperature variation, suggesting a close relation with the dynamics of the Mesosphere-Lower Thermosphere Region (MLT). For middle latitudes, the results shows no clear correlation, it can be due to the presence of planetary waves with periods around 10, 12, 16 days which might affect the seasonal behavior of the nighttime lower ionosphere. Since planetary waves are very predominantly of tropospheric origin, this result is an evidence of the vertical couplings in the atmosphere-ionosphere system.

1 Introduction

The lower ionosphere at heights between 60km and 100km includes the D-region and the bottom of the E-region. This ionospheric region has been probed by monitoring the energy released during lightning discharges within ELF (Extremely Low Frequency: 3-3 kHz) and VLF (Very Low Frequency: 3-30 kHz) bands. These waves propagate by multiple reflections and its cut-off frequency (f_{cn}) is related to the effective reflection height (h_N) of the lower ionosphere (called here as nighttime lower ionosphere height) by $f_{cn}=nc/2h_N$ where n is the cut-off frequency mode number; c is the speed of the light in vacuum. Since f_{cn} is related to h_N, and hence to the electron density, it provides valuable information of the lower ionosphere.

Some studies have used daytime and nighttime VLF narrowband amplitude variation to study a possible relation between the lower ionosphere and the dynamics of Mesosphere-Lower Thermosphere (MLT) region [1, 2, 3]. Since these studies have used VLF narrowband signals, their observations are limited along the propagation path. In addition, these long propagation paths covers different latitudes, hence the result represents an averaged observation along the path which can be somewhat smoothed. In this paper we analyze the nighttime lower ionosphere height behavior in order to investigate its possible relation with the dynamics of Mesosphere-Lower Thermosphere (MLT) region.

2 Data and Methodology

We use data from DEMETER (Detection of Electro-Magnetic Emissions Transmitted from Earthquake Regions) satellite, which has provided a continuous observations on the ionospheric waves at 10:30 and 22:30 Local Time (LT). We have focused on Power Spectra Density (PSD) data from the ICE (Instrument Champ Electrique) experiment [4] in survey mode for ELF/VLF band range (20 Hz - 20 kHz) and from 2006 to 2009 (04 years) which is under low solar activity.

Since the Solar Lyman-α radiation is the most important ionization source of the lower ionosphere; during daytime it may overwhelm any other phenomena forcing this region. Therefore, we use nighttime data to describe the lower ionosphere and its variation is compared to the nighttime mesospheric temperature which is commonly used to describe the dynamics of the MLT region. An example of the ICE-VLF spectrogram from DEMETER data can be seen in Figure 1. The cut-off frequency is clearly distinguishable at around 1.7 kHz.

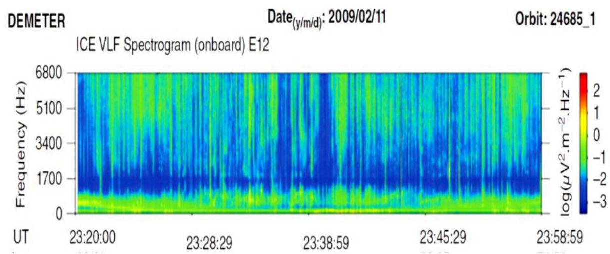

Figure 1. ICE-VLF spectrogram of a nighttime half orbit recorded by DEMETER. It corresponds to February 11, 2009. The cut-off frequency of the Earth-ionosphere cavity can be clearly seen at around 1.7 kHz (modified from [5]).

Atmospheric temperature data is obtained from SABER (Sounding of Atmosphere using Broadband Emission Radiometry) instrument on-board the TIMED (Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics) satellite (V2.0, Level 2A, http://saber.gats-inc.com) [6].

For estimating the nighttime lower ionosphere height, we use the methodology as used in [7] and earlier proposed by [8]. This method focuses on detecting the first nighttime cut-off frequency (fc ~ 1.7 kHz) of the Earth-Lower Ionosphere Waveguide which is seen as a minimum of energy (see Fig. 1), then that energy minimum is detected, hence *fc*, and h_N is calculated using the relation $fc=nc/2h_N$.

We define the region for studying as shown in Figure 2. It is located between 30°E and 60°E of longitude and from 50°S to 50°N in latitude. This region is divided in 5 boxes (dashed lines) that covers middle-latitudes [±30°, ±50°], low latitudes [±10°, ±30°] and equatorial latitudes [-10°, +10°]. For each box we take the daily nighttime ICE-VLF nighttime spectra. Because the level 1 ICE-VLF spectra are in log($mV^2m^{-2}Hz^{-1}$) units, we linearize them and normalized to its mean. Finally, all the spectra which belong to the same region are daily averaged and then the local minimum is detected.

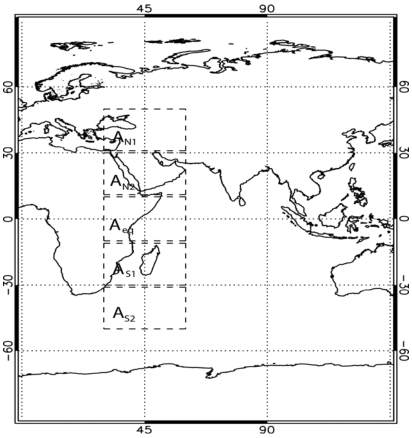

Figure 2. Map of the regions under study. Longitudes between [30°E, 60°E] divided in 5 boxes (dashed lines), covering middle-latitudes [±30°, ±50°], low latitudes [±10°, 540 ±30°] and equatorial latitudes [-10°, +10°].

3 Results

The temporal variation of h_N as a function of number of days after 01/01/2006 is shown in Figure 3. The red line illustrates the 30-days running average. From Figure 3 we note that h_N reaches typical values of the nighttime lower ionosphere [9, 10] and its temporal variation shows long-term timescales oscillations such as semiannual (SAO) and annual oscillation (AO). These periodicities are confirmed by the Lomb-Scargle (LS) periodogram as shown Figure 3 with arbitrary power units (as result of the LS periodogram procedure). The dashed blue line denotes 95% confidence level. Vertical black dashed lines illustrate periodicities at 180 and 365 days which correspond to the semiannual and annual oscillation, respectively. Note that for equatorial, low and middle latitudes the SAO is dominant except for A_{S2}[50°S, 30°S] where the AO becomes dominant. These results agree with those earlier reported and widely discussed by [8].

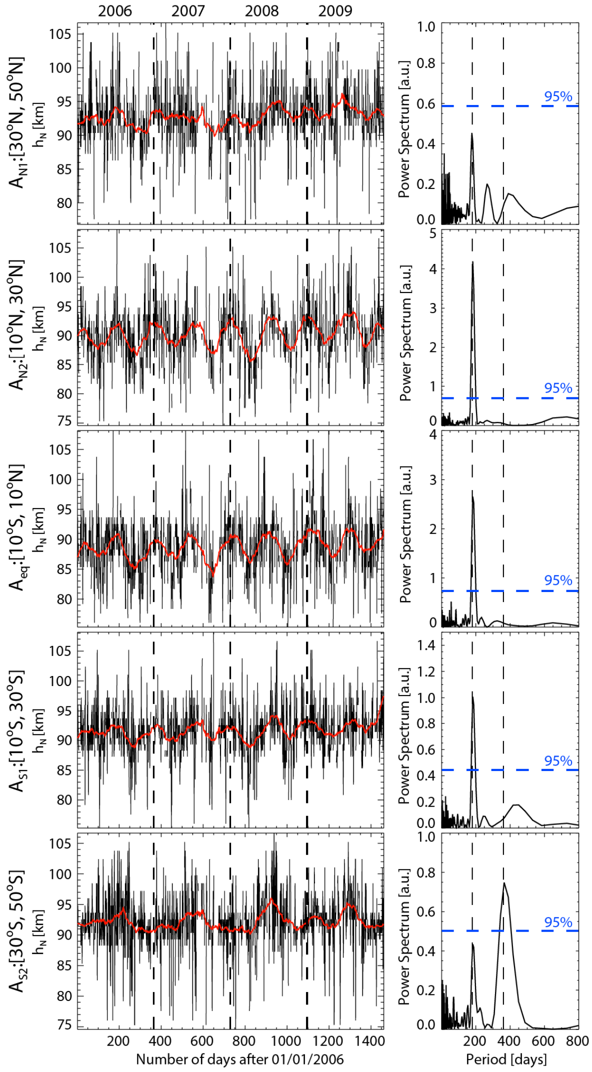

Figure 3. Left panels show the temporal variation of the nighttime lower ionosphere height (h_N) as a function of number of days after 01/01/2006. The 30-days running average is illustrated by red solid line. Right panels show Lomb-Scargle (LS) periodogram of h_N.

To study the relation between the dynamics of the MLT region and the nighttime lower ionosphere, we compare h_N with the nighttime mesospheric temperature estimated for different ranges of altitudes between 80km to 100km. This procedure is done in order to find the highest correlation. The correlation analysis is performed using monthly mean values from smoothed h_N and mesospheric temperature data. The result is shown in Figure 4 where the range of altitudes (h) used for estimating mesospheric temperature mean values and Pearson correlation coefficient (R) are shown in blue.

We note that h_N shows mostly negative correlation with the mesospheric temperature and it is significant for equatorial [10°S, 10°N] and low [±10°, ±30°] latitudes with R~-0.7, while for middle-latitudes [±30°, ±50°] no significant correlation is observed.

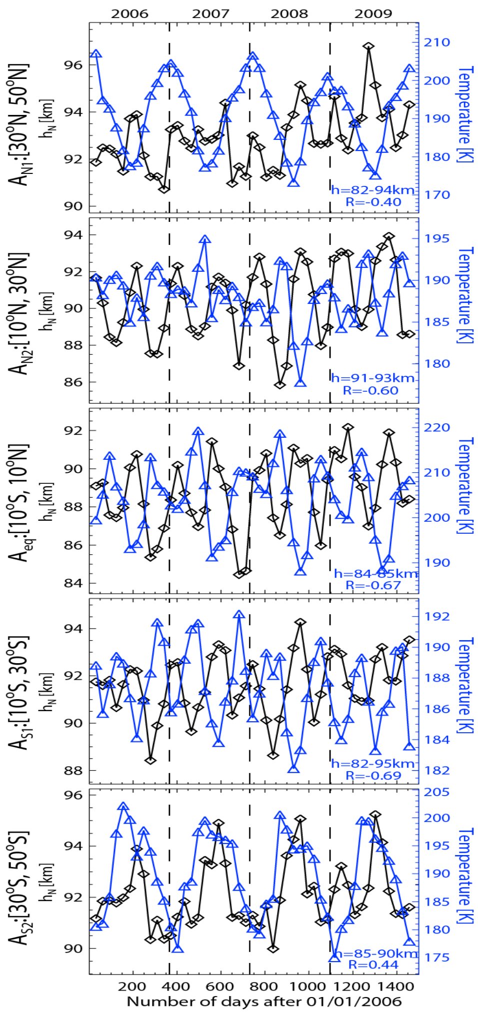

Figure 4. Monthly mean values for h_N (black symbols) and mesospheric temperature (blue symbols). The altitude range (h) where mesospheric temperature is estimated and the Pearson's coefficient (R) are shown in blue.

4 Discussion

The global lightning activity has shown semiannual and annual oscillations in the tropics and mid- to high latitudes, respectively [11], it might explain the SAO and AO observed in h_N. However, lightning activity is more important over land areas than over oceans and the oceanic lightning activity is fairly constant all over the year [11]. Hence, the SAO and AO observed, even over oceanic regions, together with significant correlation between h_N and the mesospheric temperature (principally for equatorials and low latitudes) might suggest a coupling between the nighttime lower ionosphere and the dynamics of the MLT parameters whose magnitudes and oscillations (such as SAO and AO) are drove mainly by dynamical processes such as winds, tides, planetary waves and gravity waves.

For middle-latitudes we found not significant correlation. This result is very suggestive due to the fact that for these latitudes the temperature exhibits faster fluctuations during the local wintertime (between May to August for Southern Hemisphere) as shown in Figure 5. Then, a possible explanation for this result is that atmospheric forcing from bellow might disturb the seasonal dependence resulting in low correlation. It is known that Planetary Waves (PWs) can break near the Mesopause region depositing energy and momentum, changing the conductivity profiles and electron-neutral collision frequency [12].

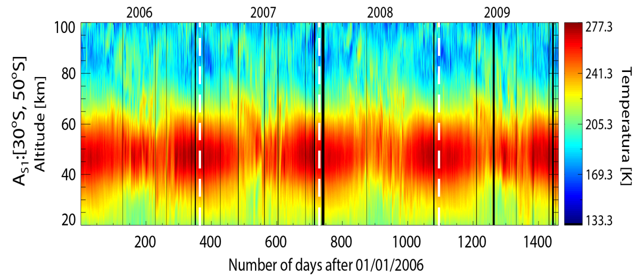

Figure 5. Variations of the temperature for [30°E, 60°E], [30°S, 50°S] from 2006 to 2009.

In order to study the presence of PWs forcing the nighttime lower ionosphere, we apply the wavelet analysis to h_N at middle-latitudes [30ºS, 50ºS]. We apply this procedure using data from 2006 because it has less data gaps than other years. We use a Morlet mother wavelet with frequency parameter equal 6 and significance level of 95% (for details see [13]). The same procedure is done to the stratosphere temperature estimated at h= 33 km. The result is shown in Figure 6 where vertical dashed lines delimited the local wintertime. The power spectrum density (PSD) for each parameter is also shown.

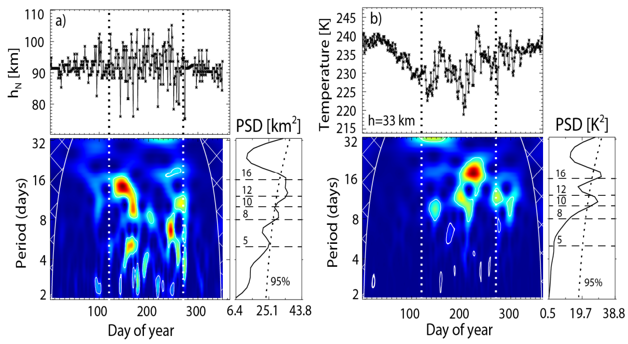

Figure 6. Wavelet analysis for h_N (panel a) and stratospheric temperature at h = 33 km (panel b) during 2006.

From Figure 6 we note that h_N fluctuates mostly with periods around 8, 10, 12 and 16 days while the stratospheric temperature shows components with periods around 10, 12 y 16 days, all components presenting stronger activity during the local wintertime. These results show that periodic components detected in the stratospheric temperature present the same behavior observed in the nighttime lower ionosphere, which reinforces the evidence for the coupling between the lower ionosphere and the stratosphere. This result is in agreement with that reported by [1].

The large fluctuations observed can be due to electron density enhancements in the nighttime lower ionosphere as a consequence of the redistribution of nitric oxide (NO) (which is the primary source of electrons in the lower ionosphere) transported from higher to middle-latitudes under the influence of planetary waves [1].

5 Conclusions

The 4-years study of the nighttime lower ionosphere height estimated from DEMETER satellite data is presented in this work. This analysis is done for a region between 30°E and 60°E for equatorial, low and middle latitudes. Semiannual an Annual Oscillations are observed in h_N, being SAO dominant for equatorial, low and middle latitudes while AO becomes significant for mid-latitudes. The fact that h_N shows long-scale oscillations, even over oceanic regions, and significant correlation with the mesospheric temperature (mainly for equatorial and low latitudes), it might evidence a coupling between the nighttime lower ionosphere and the dynamics of the MLT region.

It is proposed that atmospheric forcing from bellow at middle latitudes might disturb the seasonal behavior of the nighttime lower ionosphere, resulting thus low correlation between h_N and mesospheric parameters. We found that during local wintertime h_N and stratospheric temperature shows strong fluctuation with similar periods around 10, 12 and 16 days which has been related to planetary scale wave activity with typical periods around 5, 10 and 16 days. This result suggests a close relation between the nighttime lower ionosphere and the dynamics of the lower-lying of the atmosphere which appears to be strong during local wintertime when high upward propagating planetary wave activity is commonly observed.

Long-term observations of atmospheric waves disturbing the lower ionosphere are still necessary in order to characterize the coupling between different layers of the atmosphere. Simultaneous observations in both hemispheres are also desirable for a better understand of inter-hemispheric connections.

6 Acknowledgements

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7 References

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